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Progress Report
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Preliminary Findings of the Photovoltaic Cell Calibration Experiment on Pathfinder Flight 95-3

by

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Objective

The objective of the photovoltaic(PV) cell calibration experiment for Pathfinder was to develop an experiment compatible with an ultralight UAV to predict the performance of PV cells at AM0, the solar spectrum in space, using the Langley plot technique. The Langley plot is a valuable technique for this purpose and requires accurate measurements of air mass(pressure), cell temperature, solar irradiance, and current-voltage(IV) characteristics with the cells directed normal to the direct ray of the sun. Pathfinder's mission objective(95-3) of 65,000 ft. maximum altitude, is ideal for performing the Langley plot measurements. Miniaturization of electronic data acquisition equipment enabled the design and construction of an accurate and light weight measurement system that meets Pathfinder's low payload weight requirements.

Experimental Configuration

Figure 1 provides a schematic representation of the PV cell calibration experiment control module mounted in the starboard pylon on Pathfinder. The module contains an ONSET Computer Corporation TattleTale Model 8 Motorola 68332 microprocessor controlled data acquisition module with 1Mb of data storage capacity. Four of the A/D channels on the Model 8 were multiplexed to provide 16 differential input channels. A Motorola MPX5100A silicon piezoelectric pressure transducer was used to measure pressure (1 channel). Temperature measurements were made with a platinum RTD on the cell mounting plate(2 channels). Solar irradiance was measured with a thin film thermopile, also on the cell mounting plate, calibrated with the NASA Spectrosun AM0 solar simulator at Lewis(1 channel). The remaining 12 channels were used to measure cell voltage(1 channel/cell) and cell current(1 channel/cell) using a precision current sensing resistor sized for the short circuit current of each cell. The variable bias voltage to measure the cell IV curves was generated with a custom switchable dual output power supply including a 12 bit D/A controlled by the Model 8. An embedded program written in BASIC running autonomously on the Model 8 managed all timing and data acquisition functions during flight. Two lithium-sulfur dioxide battery packs (+/- 14.5 volts) and two lithium 9 volt cells in parallel control module powered the main circuitry and the Model 8. The control module also contains solid state switching devices to open and close the wire impactor which is powered by Pathfinder.

Figure 2 shows a schematic representation of the aluminum cell mounting plate mounted on the wing trailing edge just aft of the starboard pylon. The mounting plate was electronically connected to the control module with a 50 conductor shielded cable. Six(6) 2 x 2 cm cells in specially fabricated holders were symmetrically mounted on the plate. The cells on flight 95-3 represented state of the art technology and included three tandem

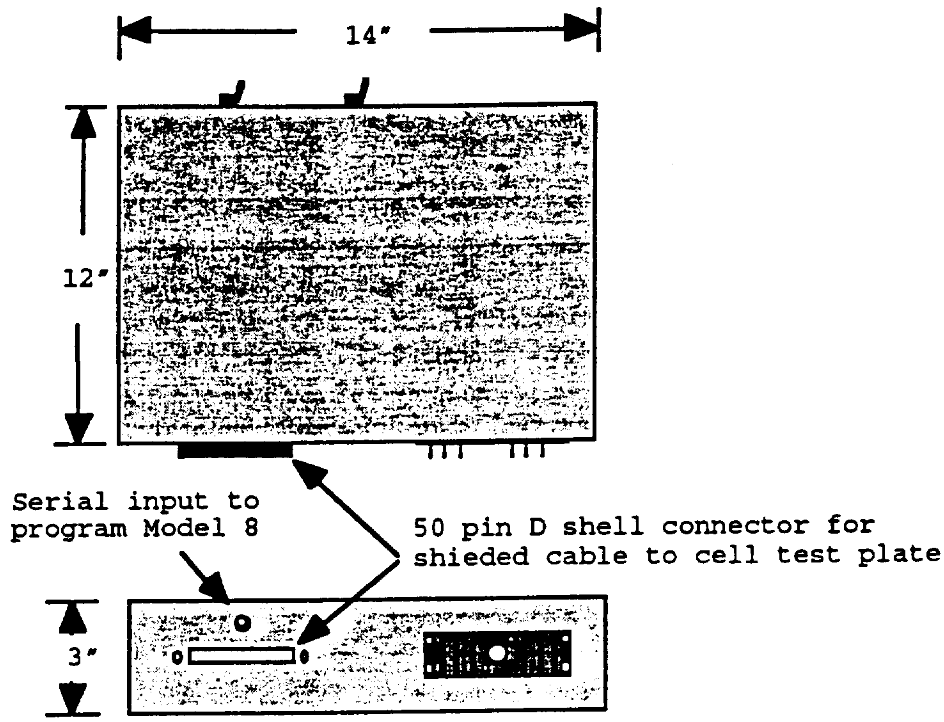

Figure 1. Schematic representation of control module

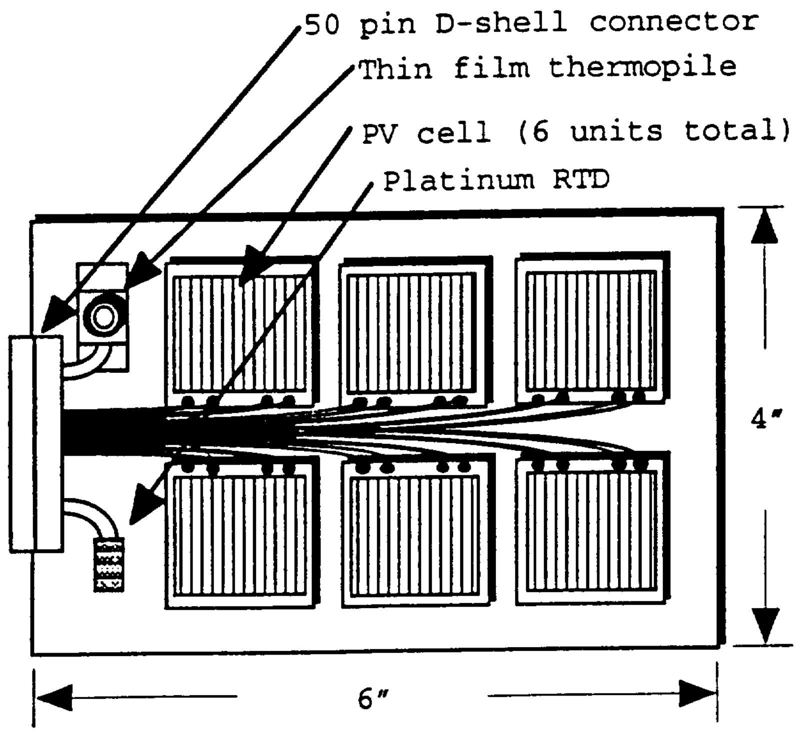

Figure 2. Cell mounting plate assembly (mounted on trailing edge of wing)

cells, InP/InGaAs, GaInP/InP(2 units), and GaAs/Ge, and Si and InP single junction cells. The plate was mounted at an angle to the trailing edge of the wing to coincide with the anticipated declination angle of the sun at solar noon. Azimuth angle of the mounting plate was dependent on the orientation of Pathfinder during flight.

Results

The experimental results from the first flight, Pathfinder flight 95-3, show that the experiment performed the measurements as programmed for the duration of the flight. The data which appears in the following figures was successfully downloaded at the end of the flight by Aerovironment personnel. The results for solar irradiance, cell mounting plate temperature, pressure, and IV measurements during $(0 < t < 14400$ sec) and $(28800 < t < 39600$ sec) are consistent with pre-flight tests conducted at Dryden at ground level. Although the control module and the Model 8 appear to have operated for the duration of the flight, the unit appears to have been affected by environmental extremes during the high altitude portion of the flight$(14400 < t < 28800$ sec). Resistance heaters were installed on the control module before the flight, however due to time constraints, no preflight testing for adequate environmental control of the electronic systems was performed. The following data is presented to coincide with the time sequence of the Pathfinder flight data in Memo No. AV-ERAST-16 dated 9/22/95 i.e. t=0 sec @ 15:59:23.77.

Figure 3 shows the measurements for pressure altitude vs time

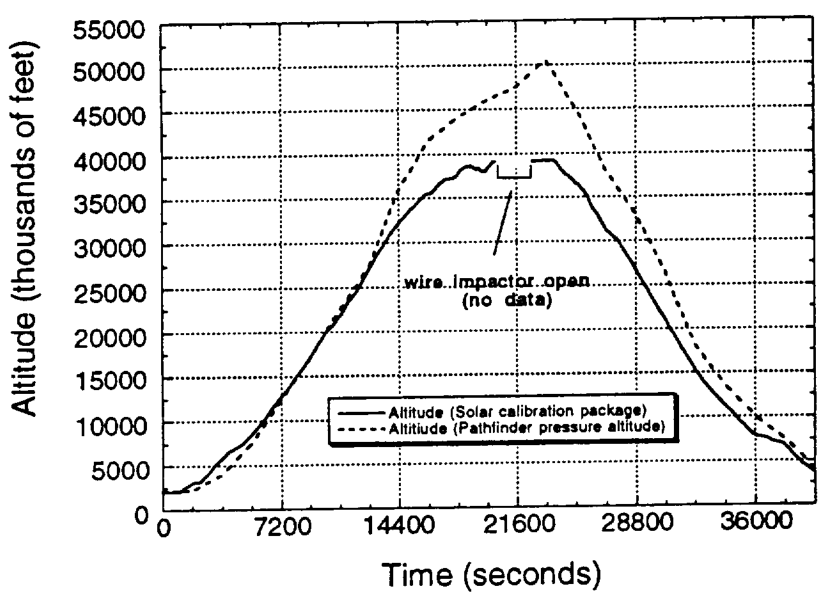

Figure 3. Pressure altitude vs time

for the flight. The altitude measurements agree well with the Pathfinder pressure altimeter results for (0 < t < 14400 sec). For (14400 < t < 28800 sec) the accuracy of the measurements deteriorates with recovery during the descent(28800 < t < 39600 sec). Although the pressures anticipated during the flight were well within the operating specifications of the silicon piezoelectric pressure transducer the performance of the transducer/data acquisition circuitry was most likely compromised by the low ambient temperatures, less than -40° C, encountered at high altitudes. Figure 3 also shows the time interval when the wire impactor was opened and other data acquisition functions were suspended.

The spatial orientation of the cell mounting plate is dependent on Pathfinder's attitude and direction, i.e. no active sun tracking is employed. For this reason the experiment was designed to provide information pertaining to the orientation of the cell mounting plate to the sun when IV measurements were made. Figure 4 shows the results for the solar irradiance vs time measured with the sun sensor. The sun sensor consists of a calibrated, temperature compensated, thin film thermopile with a collimating tube to provide an acceptance angle of 20° for incident radiation. The two markers identify the irradiance level at the start(O) and finish(X) of the IV curve measurement procedure. The figure indicates that for several series of measurements during the initial phase of the flight the irradiance level at these times was almost identical. The inset to figure 4 provides greater temporal resolution of the measurement intervals and shows the data interval selected to produce the IV curves in

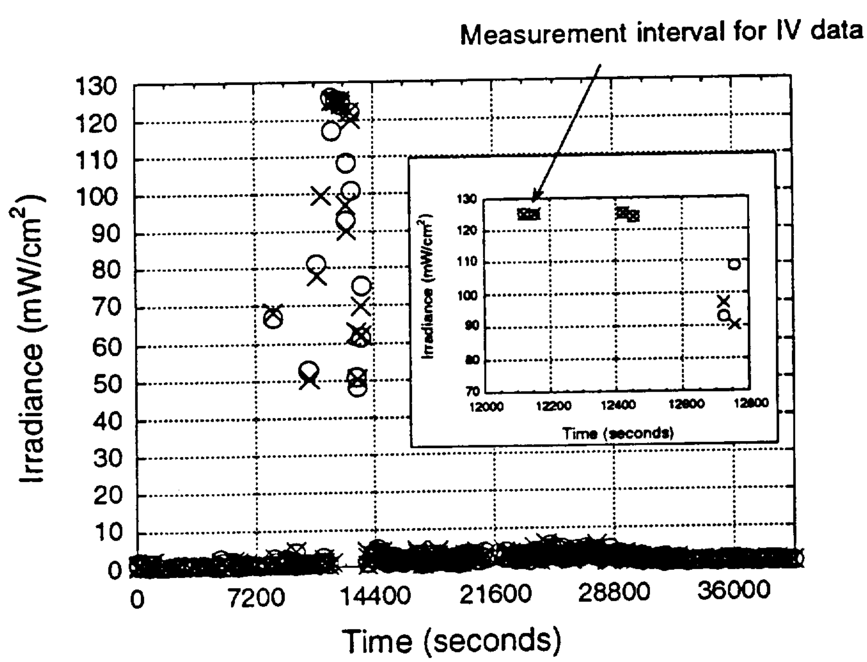

Figure 4. Solar irradiance vs time measured with the sun sensor.

figure 6. The measurements, taken at approximately 30,000 feet, were made while the control module was unaffected by low temperatures and with the direct ray of the sun normal (within 10°) to the cell mounting plate.

Figure 5 shows the cell test plate temperature in degrees F

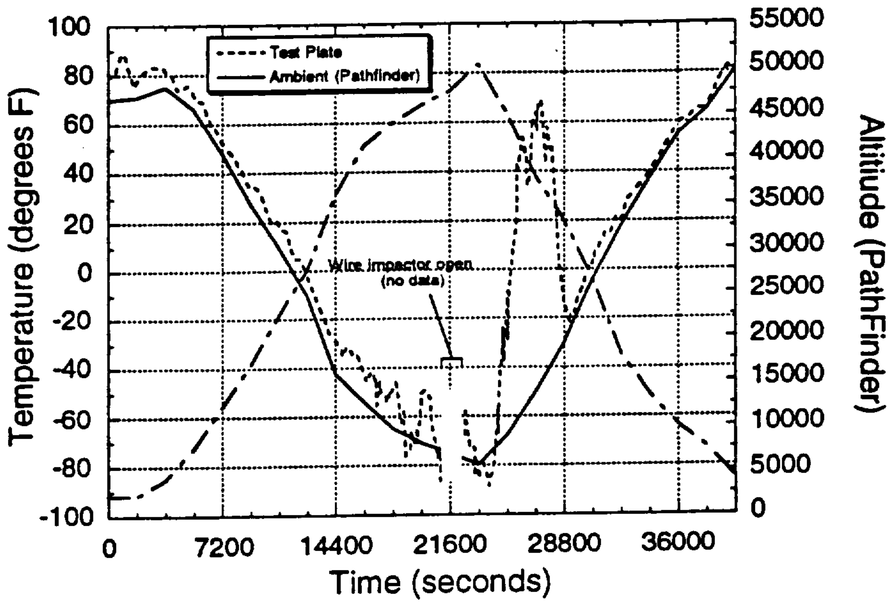

Figure 5. Cell test plate temperature vs time

and C vs time as measured by the platinum RTD. The data compares favorably with the ambient air temperature sensor on Pathfinder (reference: Pathfinder "Air Temperature Sensor Data").

Figure 6 shows the IV characteristics of the six cells for the time interval described in the discussion of figure 4. The cells survived the flight intact except for the InP/InGaAs tandem cell which suffered pre-flight mechanical damage. The effect of the fracture can be seen in fig.6(e). Without active temperature control of the cell mounting plate, the IV measurements were made under ambient conditions, approximately -10° C. For PV cell materials the open circuit voltage, V_{oc}, increases with temperature and irradiance. The short circuit current, I_{sc}, decreases with temperature and increases with irradiance. The effect of low temperature on V_{oc} and I_{sc} for the cells on flight 95-3 is consistent with theory. Post-flight measurements will be performed under standard conditions (135.7 mW/cm^2 @ 25° C) to quantify the actual difference in performance.

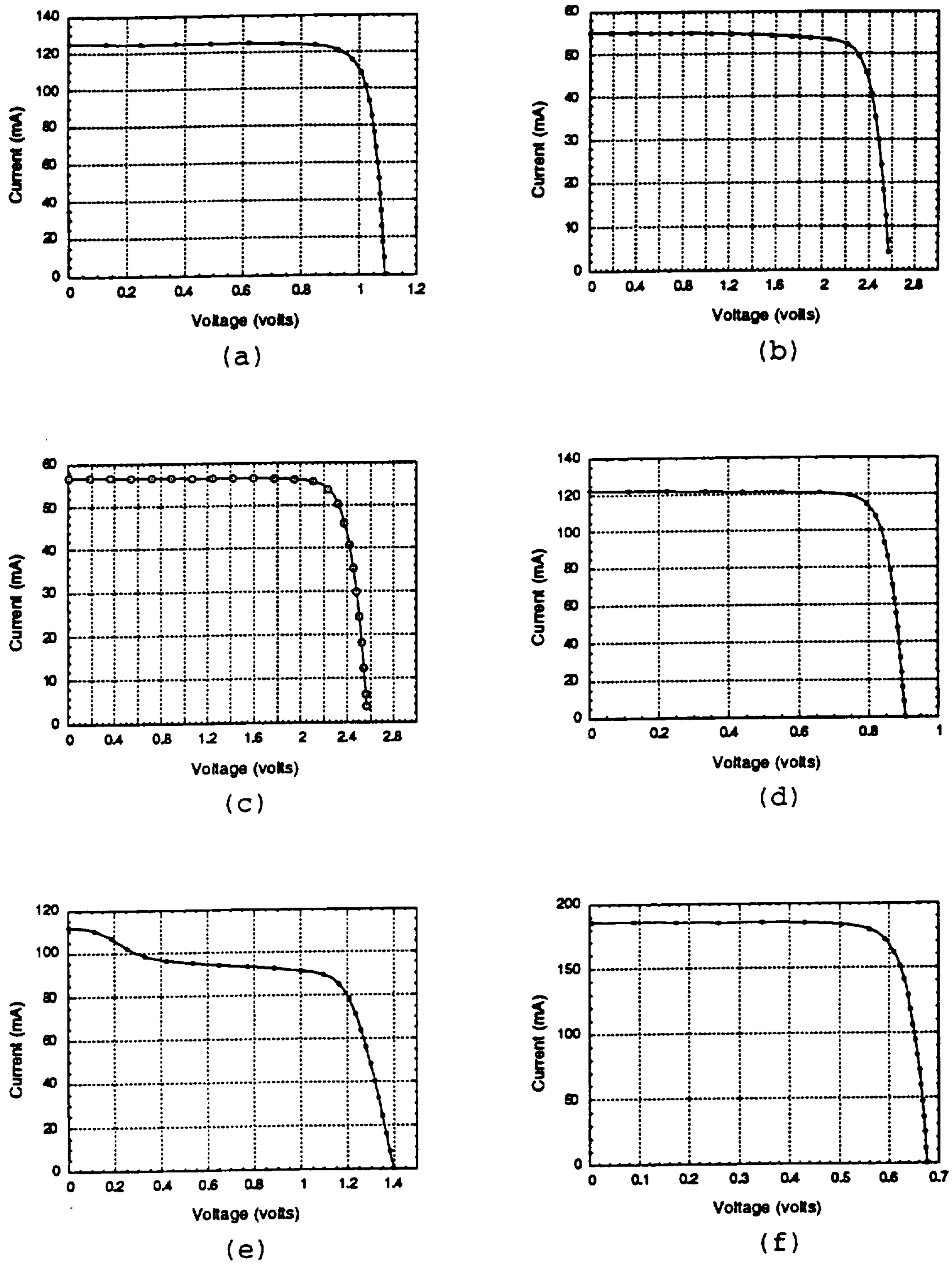

Figure 6. IV characteristics of the six PV cells on Pathfinder flight 95-3 at approx. 30,000 ft.(a) GaAs/Ge, (b) GaInP/GaAs #1, (c) GaInP/GaAs #2,(d) InP (e)InP/InGaAs Si, (f) Si

Conclusions

Initial results indicate that the experiment performed well during the period before and after the electronics were affected by the severe cold encountered at altitudes greater than 30,000 ft. With no design verification and pre-flight environmental testing of the the control module heaters this is not a complete surprise. Minor improvements(environmental control) in the electronics enclosure would easily correct this problem. During the initial and final portions of the flight i.e. altitudes less than 30,000 feet., the measurements recorded from all the transducers compare well with data from Pathfinder. Cell IV measurements during this interval were also successfully performed. Limited directional control, fixed declination angle and azimuth angle dependent on Pathfinder, limited the opportunity to perform IV measurements within a 10 degree angle normal to the direct ray of the sun for most of the flight. This was anticipated since the flight profile of Pathfinder was chosen to achieve maximum altitude and not necessarily to accommodate payload requirements. Evidence in the postflight data indicates that the wire impactor was opened for 20 minutes shortly before reaching maximum altitude.

Recommendations

Several recommendations for improving the performance of the experiment and increasing the value of the data for cell calibration standards are:

1. Add additional heater capacity/insulation on the electronics control module and thermal cycle the unit to verify operation at low ambient temperatures.
2. Add insulation and active thermal control on the cell mounting plate to maintain cell temperature at 25° C.
3. Provide sun tracking capability or upgrade the sun sensor to record the angle of the sun relative to the cell mounting plate.